Revolute Joint Motion Control System Design Based on Hydraulic Oscillation Cylinder

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Abstract. Joint is a core component of space manipulator and the foundation of space manipulator system[1]. Hydraulic manipulator is one of the key points for developing and exploring manipulators in recent years. However, servo control of hydraulic executive components still needs further studies. In this thesis, the author combines current research status of hydraulic manipulator joints and designs a kind of joint which is mechanical electrical and hydraulic driven as well as its servo motion control. Through research and experimental analysis on the joint designed in this thesis, the results demonstrate that using current hydraulic driven joint and its control system can realize basic requirements for building a hydraulic manipulator.

Introduction

Manipulators used by general service robots are mainly built by rotary joint which is composed of motor reducer and has evident advantages of high motion precision and mature control method and disadvantages of high cost and low volume-output power. Hydraulic system has advantages such as stable movement, large output power and long life time. Moreover, the system can also carry out output motion smoothly under low speed motion state to avoid phenomena such as crawl driven by motor. Applying hydraulic system to manipulator joint design can improve the performance of current manipulator joints effectively. However, the system has problems such as leakage and compressible traditional medium. Meanwhile, servo control for hydraulic executive components mostly depend on hydraulic system servo components such as servo valve and proportional valve, which results in high cost of servo components. And it is one of the reasons that limit hydraulic system to be used in manipulator joint.

Aiming at existing problems in current hydraulic joint servo control, the author designs a kind of joint which is mechanical electrical and hydraulic driven as well as its servo control methods and carries out experimental analysis for the system.

System Structure Design

Hydraulic system usually composes of five parts including power component, executive component, control component, auxiliary component and traditional medium. Control center of traditional hydraulic system's servo control lies at the servo valve which establishes a relationship among servo valve effective opening distance x, executive component output load F and output speed v. In this method, the advantage is that a mathematical model of the system could be acquired quickly by fully making use of current research achievements; but it is complicated to acquire the model's actual parameter and it is required that the hydraulic valve adopted should be servo valve or proportional valve whose spool position is adjustable.

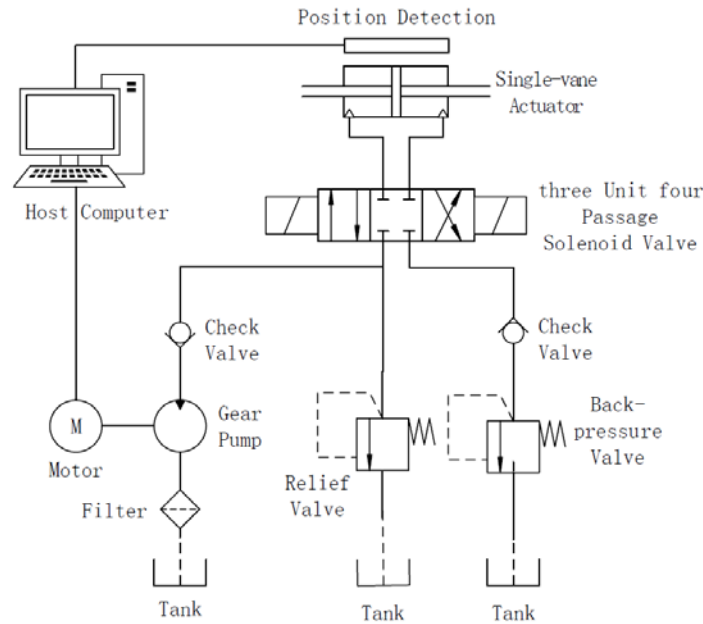Hydraulic servo system structure designed in this thesis is shown by figure 1:

Fig. 1 System Structure of Hydraulic

Mathematical equation of balanced output state for regular stretching hydraulic cylinder is as follows:

$$P_{in} \times A = F + P_{out} \times A = m \times a + P_{out} \times A$$
$$Q_{sh} = v \times A = A \times dx/dt$$

Among which, P_{in} is input port pressure, P_{out} is output port pressure, Q_{sh} is instantaneous flow, v is testing speed and A is action area. For oscillation cylinder:

$$P_{in} \times \int bdy = J \times dw/dt + P_{out} \times \int bdy$$
$$Q_{sh} = 1/2 \times w \times (r^2 - r_0^2) \times b$$

Among which, b is vane thickness, J is rotational inertia of oscillation cylinder, w is vane angular spin rate, r is maximum radius of the vane and r_0 is minimum radius of the vane.

Mathematical model for gear pump is as follows:

$$Q_{sh} = B \times w \times (2Rh + h^2 - f^2)$$

Among which, B is gear width, w is gear pump angular speed, h is gear thickness, R is gear reference radius and f is the distance between gear meshing point and pitch point.

PWM method is adopted in motor speed regulation of the structure and the relationship between PWM and output rotation rate is obtained as follows:

$$w' = w_{max} \times D_{pwm}$$

Among which, w_{max} is maximum angular velocity and D_{pwm} is duty ratio.

Combine all equations and then obtain the functional relationship between D_{pwm} and output parameter v and P_{in},

$$w/ D_{pwm} = 2 B \times w_{max} \times (2Rh + h^2 - f^2) / (r^2 - r_0^2) \times b$$

System Control Method

According to system mathematical model calculated above, control method is planned as follows in figure 2.

PID(proportion, integral, derivative) control is one of the most effective and mature plans for motor control[2]. Therefore, here we choose PID control method to regulate motion parameter. In current mathematical model of hydraulic system, f is the distance between gear meshing point and pitch point, which is constantly and periodically changed with rotation angle. Therefore, this is a second-order system, not an ordinary linear system. For non-linear system PID parameter setting, genetic algorithm can be used for parameter optimization[3,4].
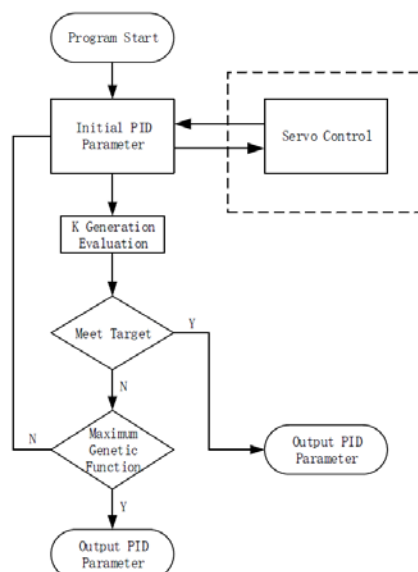
Fig. 2 Flow Chart of Control Algorithm

After k times of iteration, if the PID parameter acquired could meet motion performance requirements, then PID at this time is output; if after n times of iteration, the system still cannot meet motion performance requirements, then original PID parameter will be the setting result.

Experiment and Analysis

Repeated positioning experiments as follows are carried out to verify the effectiveness of system principle and control method.
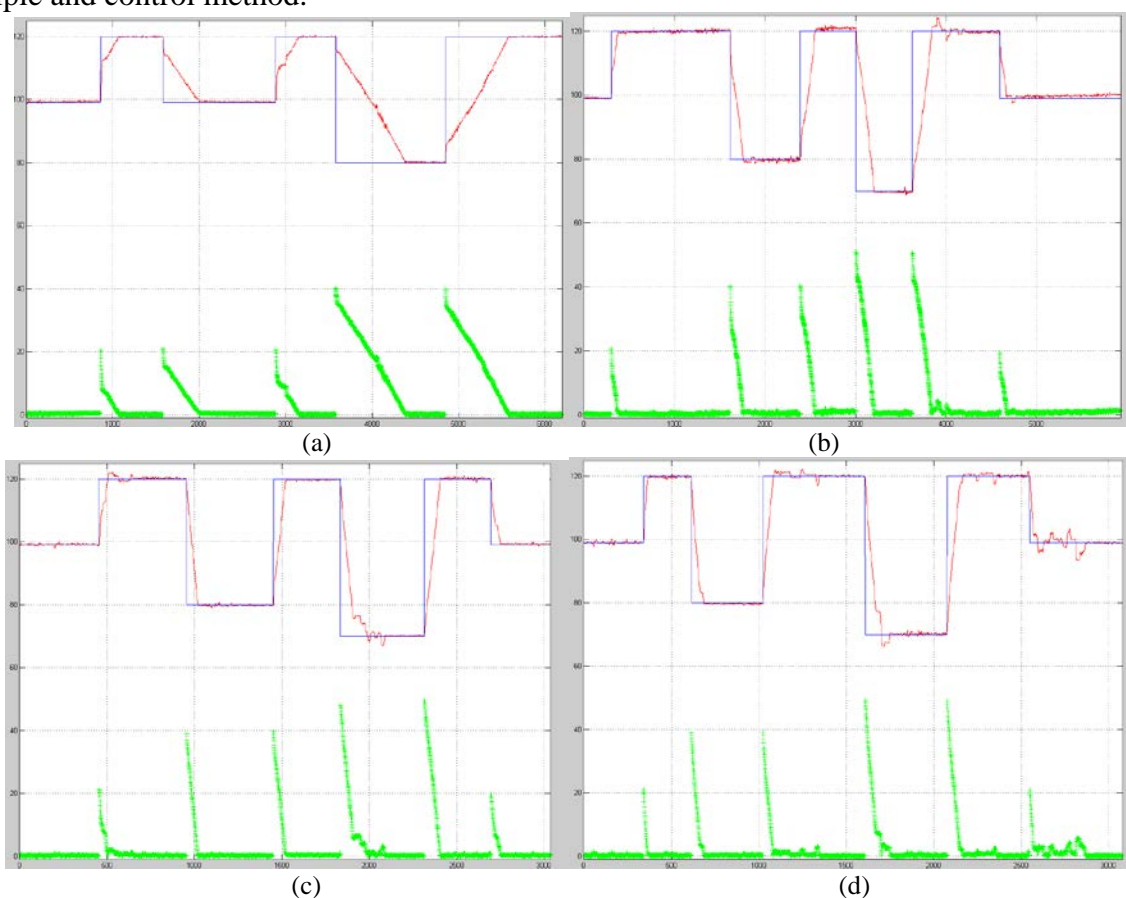

(a)

(b)

(c)

(d)

Fig. 3 Repeated positioning accuracy under different load
(a) load of 2kg (b)load of 1kg (c)load of 0.5kg (d)no-load

From Figure 3, we can see that under different load, final position error for the joint is basically 0 and once there is enough time, it can reach accuracy of the terminal position. Meanwhile, different time is needed to reach a stable state under different load, and the more the load is, the longer the time is needed.

In order to verify the accuracy detected by the system, a goniometer with 2 free degrees is used to detect the angular changes in actual motion. The experimental results are as follows:

Table 1 Measurement of angles

position	(a)	(b)	(c)	(d)	Δ_{max}
99	-6.90	-7.01	-6.84	-7.06	0.22
120	+15.22	+15.21	+15.47	+15.23	0.26
80	-26.51	-26.75	-26.69	-26.85	0.34
120	+15.20	+15.42	+15.17	+15.33	0.25
70	-35.92	-35.80	-35.97	-35.95	0.17
120	+15.27	+15.22	+15.30	+15.32	0.10
99	-6.93	-6.85	-6.89	-6.92	0.08

Summary

Experimental data show that, while oscillation cylinder is driven to do pendulum motions by gear variable pump system, effective repeated positioning accuracy can be guaranteed under different load on the basis of current control algorithm.

1. Stable angular error of oscillation cylinder is less than 0.5° under different load, which accords with general oscillation joint accuracy. Namely, this system and its control method are effective

2. Error between instruction precision and angle measured by outer angle measurement instrument always remains between 1°-2° during the experiment, which shows that there is error in the setting degree range of the built-in program

3. Error absolute value is in linear distribution under different load and the level of the straight line tilt decreases while the load increases, which means the slope will be lower (the slope is negative at this time)

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